Mars Global Surveyor
Ka-Band Data Analysis

David D. Morabito, Stan Butman, and Shervin Shambayati
Jet Propulsion Laboratory
California Institute of Technology

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INTRODUCTION

- Theoretically Ka-band (32 GHz) provides an 11.6 dB (factor of 14) advantage over X-band (8.4 GHz) as a telecommunications link frequency
- In practice, this advantage is reduced to 6 to 8 dB due to increased atmospheric and amplifier noise at Ka-band and DSN antenna imperfections, which are less significant at X-band
- This link advantage results in spacecraft mass and power savings and/or higher data rates
- As link frequency increases, antenna pointing and increased susceptability to atmospheric effects become greater concerns.
- An analysis of simultaneous Ka-band and X-band Mars Global Surveyor (MGS) data acquired between 1996 and 1998 demonstrated this link advantage using a 34-m beam waveguide (BWG) ground antenna
- The carrier frequency data were also analyzed.
  - Charged particles effects become greater as the spacecraft gets nearer the sun in angle.
  - As the higher Ka-band frequency is less susceptable to charged particle effects, it can be used to remove non-dispersive effects from the X-band link allowing these effects to be probed.

MGS Ka-Band Link Experiment

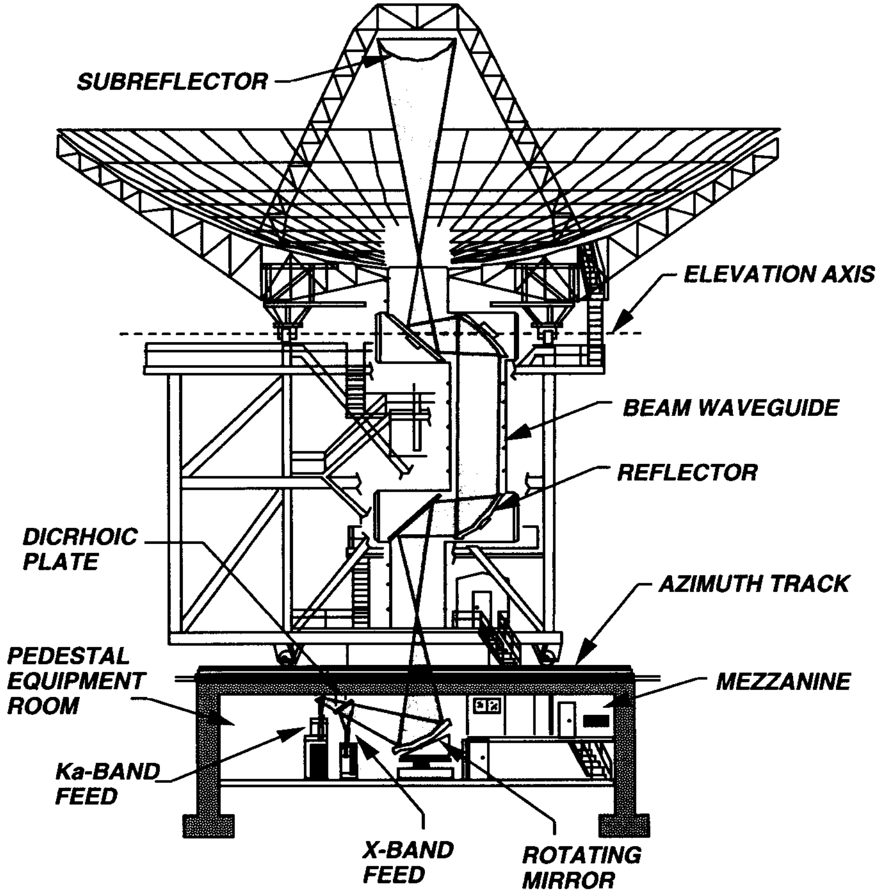
- The Mars Global Surveyor (MGS) Spacecraft Carries an Experimental Ka-band (32 GHz) Telecommunications Link in addition to the primary X-band (8.4 GHz) downlink
- The Ka/X Signals are simultaneously transmitted from a 1.5-meter High-Gain Antenna (HGA) on MGS and are received by a 34-meter beam-waveguide antenna (BWG) located in NASA's Goldstone DSN complex
- The KaBLE-II Experiment allows the performances of the two signals to be compared under nearly identical conditions
- The two signals have been regularly tracked between December 1996 and December 1998
  - Carrier signal level data (Pc/No)
  - Frequency and phase data
  - Ranging Demonstration
  - Telemetry Demonstration
- Measurements confirm that Ka-band could increase data capacity by at least a factor of three (5 dB) compared to X-band
  - Reduce cost, power, mass, and volume of future space missions

MGS/KaBLE-II Spacecraft Configuration

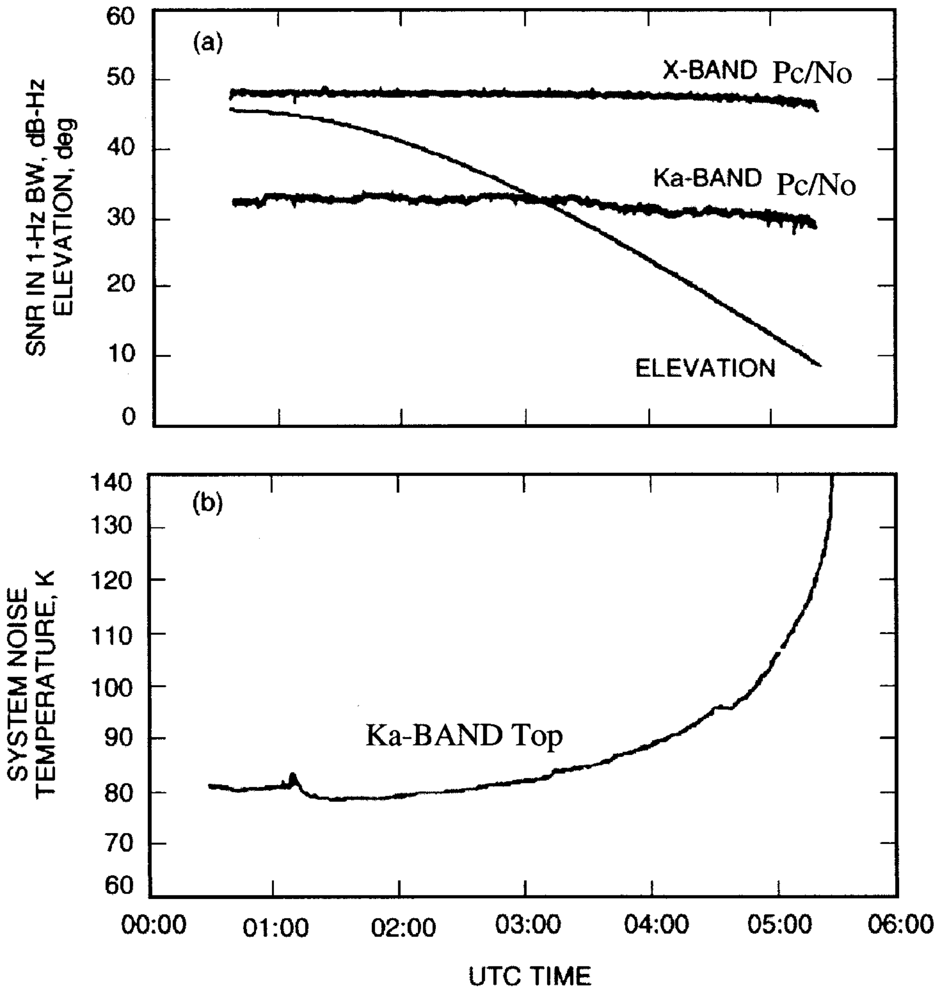
- MGS was conceived as a low cost rapid replacement for Mars Observer (MO)
- MO carried KaBLE-I
  - KaBLE-I functioned well and produced reasonable results during cruise
  - Had limitations
- MGS has increased Ka-band EIRP
  - Uses HGA instead of backside of subreflector
  - 1.2 W transmitted power instead of 25 mW
- MGS transmits within DSN allocation band
  - frequency within 31.8-32.2 GHz, instead of at 33.7 GHz
- MGS Ka-band downlink frequency can be configured in sever[illegible]
  - Can [illegible] coherent with X-band downlink
  - Can [illegible] combination of USO and VCO

DSS 13 R&D Beam Waveguide (BWG) Antenna

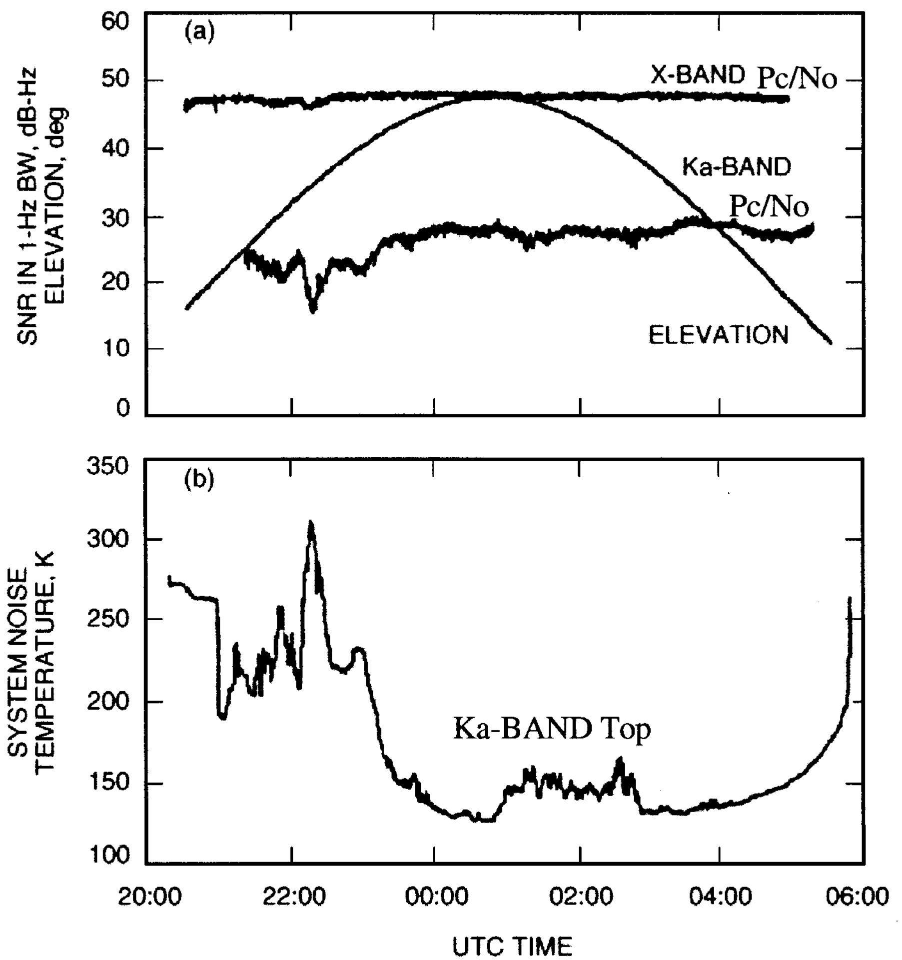
- R&D 34-m BWG antenna was built as a prototype for the evolving DSN BWG subnet
- Subterranean pedestal room provides stable environment for feed, receiver and electronics development
- Provides easy access to multiple development stations at feed ring located in subterranean pedestal room
- Lower maintenance costs compared to non-BWG antennas
- Less susceptible to weather, for example, lower attenuation during rain



Ka-band and X-band Carrier Pc/No and Ka-band Top for Clear Weather Pass (97-212)



Ka-band and X-band Carrier Pc/No and Ka-band Top for Rainy Weather Pass (97-203)



MGS/KaBLE-II Link Advantage

- Measured Ka-band and X-band Pc/No values are differenced and adjusted to correct for preventable deficiencies at both bands
    - Assume equal spacecraft transmitted power, HGA efficiency and circuit loss
    - For projected future LNAs, Top over each pass adjusted accordingly
    - Backed out carrier suppression due to telemetry and ranging modulation
    - Additional correction applied to Ka-band signal strengths acquired with higher 320 kHz telemetry subcarrier frequency and (80 x 4) deg modulation index
    - Additional correction applied to one-way data.
- For cruise data acquired before 97-255 (HGA mispointing errors assumed to be minimal):
    - Average projected link advantage = 6.6 +/- 1.4 dB (55 passes)
- For data acquired after Mars Orbit Insertion, 97-255:
    - Projected link advantage degrades due to higher spacecraft pointing errors, and degraded Ka-band equipment performance

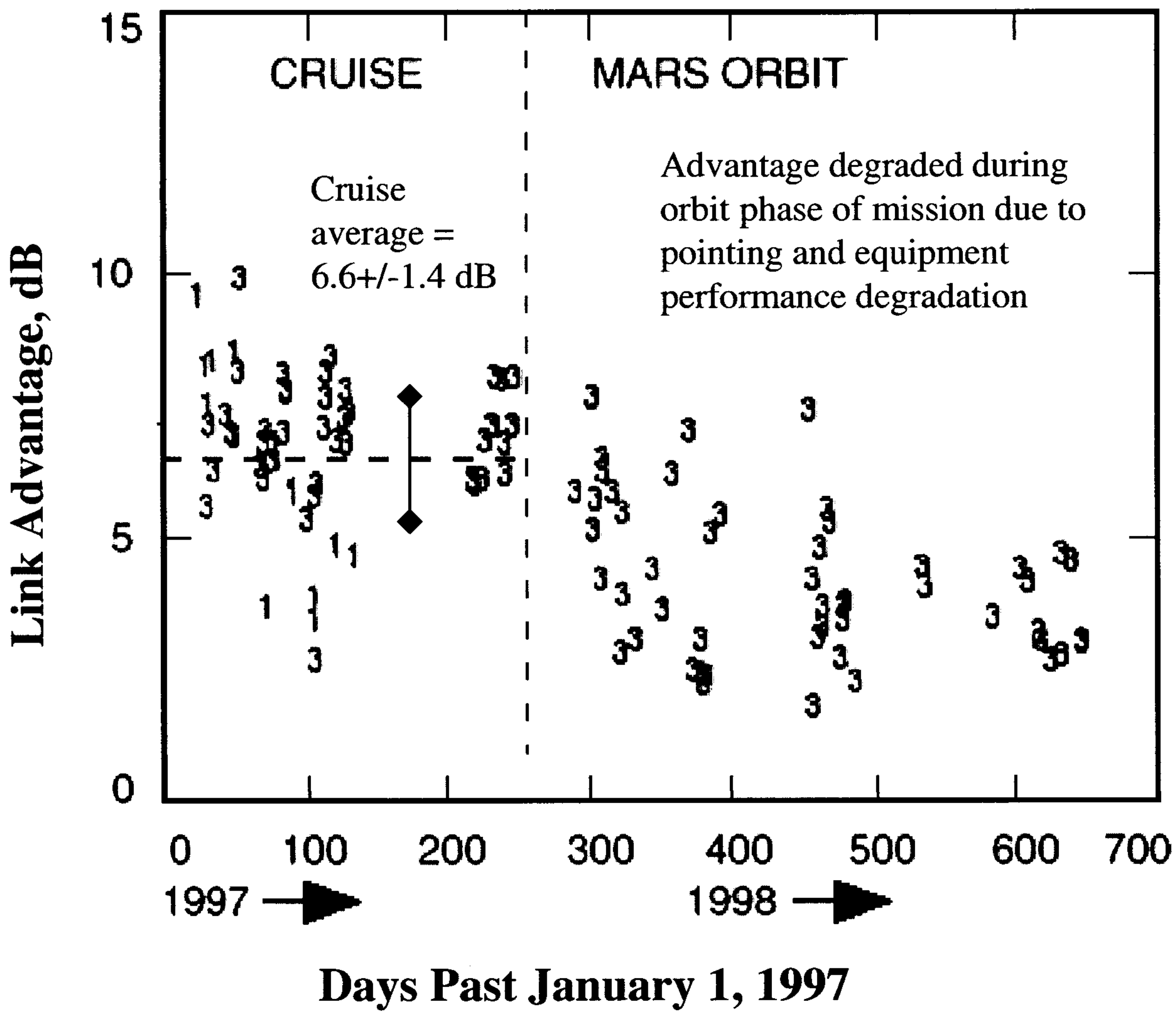
MGS/KaBLE-II Link Advantage
Pass 97-232, 60 Deg Mod Index Case

	X-band	Ka-band	Delta
Measured Pc/No	46.6 dB-Hz	32.2 dB-Hz	-14.4 dB
Power	25 W	1.2 W	13.2 dB
Antenna Gain	39 dBi	49 dBi	1.6 dB
Circuit Loss	1.0 dB	3.5 dB	2.5 dB
Net "EIRP" correction			17.3 dB
Ranging Suppression	0.2 dB	3.4 dB	3.2 dB
TLM Suppression	6.4 dB	7.0 dB	0.6 dB
LNA Temperature	3.3 dB (49K)	2.2 dB (82K)	-1.1 dB
NET ADVANTAGE			5.6 dB

Note - LNA Correction for X-band = -10 log[(Top - 26)/Top]

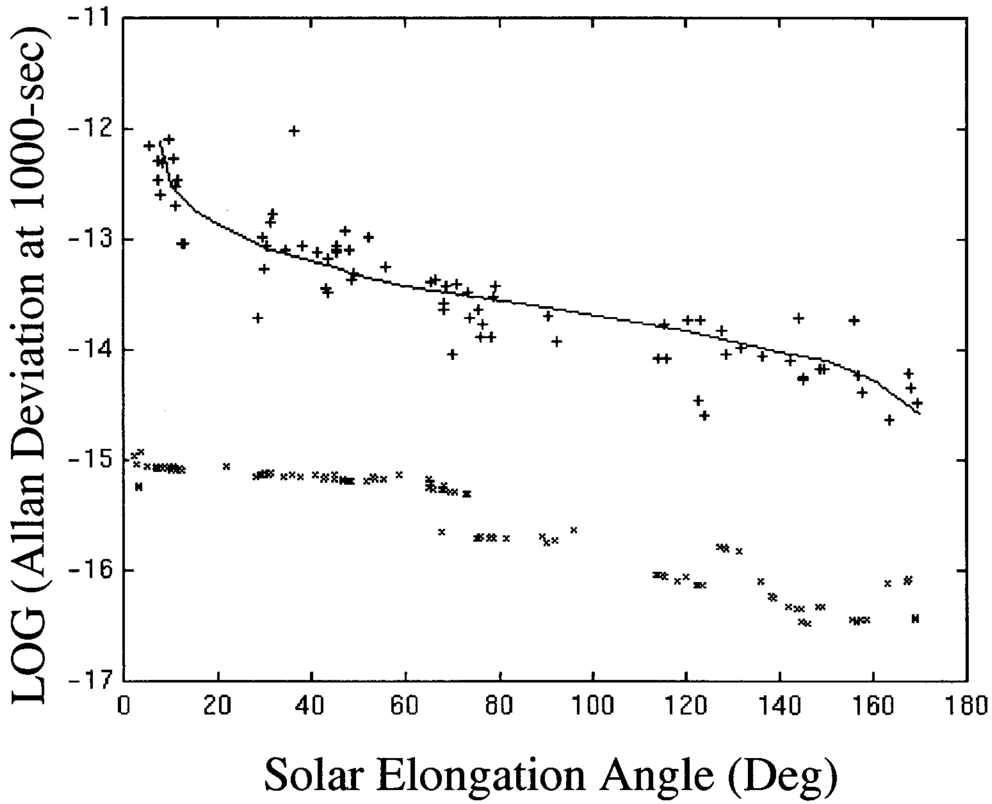
Ka-band = -10 log [(Top - 33)/Top]

MGS Ka-band/X-band Projected Link Advantage



MGS/KaBLE-II Frequency Data

- Analyzed frequency data where Ka-band is coherent with X-band
- Residuals for individual frequency bands dominated by
  - thermal noise
  - USO
  - Dynamic Spacecraft Motion
- Difference residuals (f_x - $f_{Ka}/3.8$)
  - All non-dispersive noise sources cancel (dynamic spacecraft motion, neutral atmosphere, frequency standards, etc.)
  - Remaining noise sources are thermal noise and charged particles
    - Thermal noise significant at short time scales
    - Charged particles significant at high time scales
  - Difference frequency is a measure of the charged particle effect on the X-band link
  - Allan deviations at 1000 sec decreases with increasing SEP angle
  - 1000-s Allan deviation of 6×10^{-15} is in agreement with predicted value in anti-solar direction

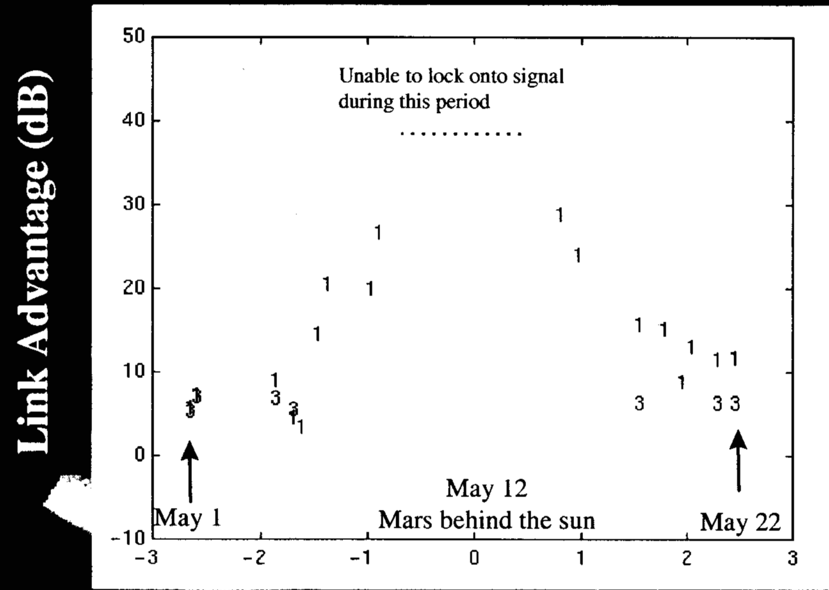


Symbol Key -
\+ Allan Deviation Measurements at 1000-s of f_x - $f_{Ka}/3.8$ frequency difference
* Estimates of Thermal Noise using Pc/No
Solid curve - Armstrong et. al. 1979 Viking S-band/X-band data acquired between 1976.3 to 1978.3 (scaled appropriately)

MGS/KaBLE-II Solar Corona
May 1998

- Data were acquired during May 1998 Solar Conjunction when MGS was angularly near the sun
- Experiment demonstrated that Ka-band signal was more easily maintained than X-band signal
  - Ka-band signal is less affected by sun's corona.
  - Increased degradation of X-band signal due to spectral and angular broadening

Ka/X-band Projected Link Advantage



Solar Elongation Angle (Deg)

980505 20:37 UTC LASCO C3 image courtesy of SOHO/LASCO. The SOHO/LASCO data used here are produced by a consortium of the Naval Research Laboratory (USA), Max-Planck-Institut fuer Aeronomie (Germany)), Laboratoire d'Astronomie (France), and the University of Birmingham (UK). SOHO is a project of international cooperation between ESA and NASA.

CONCLUSIONS

- MGS/KaBLE-II Link Experiment signal strength measurements demonstrated predicted link advantage
  - A 6 to 8 dB link advantage can be realized by using Ka-band (32 GHz) as a telecommunications link frequency in place of X-band (8.4 GHz)
  - This link advantage was demonstrated using two years of MGS simultaneous Ka/X data after correcting for known equipment deficiencies
- Frequency residual measurement statistics are consistent with expected noise sources
- Lessons learned include the importance of maintaining accurate antenna pointing at Ka-band
  - At ground station use of monopulse receiver provided ~1 mdeg pointing accuracy
  - At spacecraft adequate pointing control was maintained over much of the cruise phase of the mission (within +/-0.08 deg of HGA boresight)